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Cover Page Footnote
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Chapter 27

A COMPARISON OF THREE SOIL CHARACTERIZATION METHODS ON A SOIL FORMED IN SANDY GLACIAL OUTWASH

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ABSTRACT

A field scale test was performed to evaluate three different soil sampling approaches. These included a USDA-NRCS pedon approach, a multiple increment approach, and a five-point composite approach. A 484 ft^2 plot in an upland glacial outwash plain in Falmouth, Massachusetts was subjected to these three soil characterization methods. The USDA-NRCS approach involved the excavation of a soil pit (or pedon) with soils described according to the methods outlined in the Soil Survey Manual (Soil Survey Staff, 1993). Natural soil horizons were identified and samples were collected to a depth of 4 ft. For the multiple increment samples, a 30-point grid was installed and samples were collected using a 1 in push probe. For the five-point composite, a five-point grid was installed within the plot and samples were collected with a 2.5 in bucket auger. Both the multi-increment and the five-point composite samples were taken at arbitrary depths of 0-3 in, 3-6 in, 9-12 in, 21-24 in, and 33-36 in. All samples were subjected to particle size and organic carbon analyses. The upland soil shows the effects of podzolization with some translocation of organic matter with depth in the pedon. The particle size analysis of the pedon confirms a sandy glacial outwash with a thin layer of loess in the upper horizons. The particle size analysis also shows a clear pattern of decreasing silt content with depth in the pedon. The organic carbon analysis shows both compositing approaches have greater organic carbon contents at depth compared to the soil pedon. The compositing approaches also show higher silt contents with depth compared to the

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soil pedon. The enrichment of organic carbon and silt in the lower samples may indicate a mixing of surface materials with depth for both composite methods.

Keywords: pedology, pedon, podzolization, particle size analyses, organic carbon analysis, multiple increment sampling

1. INTRODUCTION

Soil characterization is an essential part of the determination of the nature and extent of contamination in soils. Not only is it necessary to evaluate the areal distribution of contamination across a land surface, but the depth of soil contamination is also key to understanding how that contaminant is distributed in three-dimensional space. Depth characterization also provides a key parameter in determining volumes of contaminated soil. Understanding how contamination is distributed vertically requires a method that not only provides a reasonable estimate of contamination, but also elucidates the depositional and post-depositional processes responsible for the distribution of contamination with depth. This investigation compares a method used by soil scientists to describe and map soils with two methods utilized in environmental investigations; a multiple point composite approach and a multiple increment approach.

A soil formed in sandy glacial outwash was selected for sampling using the three soil characterization methods. The pedon approach entailed excavating a pedon or a roughly 1 x 1 meter (m) pit where the soil face was described using methods outlined in the *Soil Survey Manual* (Soil Survey Staff, 1993). The pedon approach characterizes a soil based on physical soil properties such as texture, structure, consistence, etc. These characteristics identify soil horizons which then determine the location of the soil samples. The composite and multiple increment approaches use arbitrary depths, and samples are collected without regard for subsurface soil properties. In this investigation a comparison of these methods is used to determine the more appropriate method of defining the distribution of soil contamination with depth.

2. SITE SETTING

The soil investigation was conducted in Falmouth, Massachusetts on Cape Cod in an upland location on a glacial outwash unit known as the Mashpee Pitted Plain (Figure 1). The geologic setting of the site is dominated by Late Pleistocene deposits attributed to a Late Wisconsinan ice front advance and retreat. Deposits on Cape Cod normally date no older than 18,000 to 22,000 years ago when the Laurentide Ice Sheet reached its maximum southward extent to the islands of

Martha's Vineyard and Nantucket (Oldale, 2001; Dyke and Prest, 1987; Fletcher, 1993). The Mashpee Pitted Plain was formed by streams that drained the Buzzards Bay and Cape Cod Bay glacial lobes whose terminal extents are marked by the Buzzards Bay and Sandwich moraines (Oldale, 2001). Many of the upland outwash plain landscapes are covered with a thin (1 to 4 ft) mantle of loess derived from the drying of abandoned braided stream channels and deposition of silt eastward as a result of prevailing westerly winds.

The investigation was conducted in a soil mapped as the Carver soil series (Fletcher, 1993). The Carver series is a very deep, excessively drained soil in broad areas primarily on outwash plains, but can also be found in areas of sandy glacial lake deposits. Slopes range from 0 to 35 percent. The Carver soil series generally has an organic surface composed of approximately 2 inches (in) of loose, undecomposed pine needles, leaves, and twigs with one inch of matted, partly- to well-decomposed organic material. The soil surface is light brownish gray very friable loamy coarse sand about 3 inches thick. The subsoil is coarse sand approximately 33 inches thick. The upper 10 inches of this subsoil is strong brown and very friable, the next nine inches is yellowish brown and very friable, and the lower 14 inches is brownish yellow and loose. The soil below 65 inches is a light yellowish brown, loose coarse sand. The Carver series is similar to the Enfield and Merrimac series with the exception that it has a lower silt content in the surface. The Carver soils are classified as mesic, uncoated Typic Quartzipsamments (Fletcher, 1993).

This investigation examined a soil developed in sandy glacial outwash in Falmouth, Massachusetts. The soil is located in an upland position on the Mashpee Pitted Plain east of the Buzzards Bay Moraine. The plain is pitted with several kettle lakes, the closest being Boa Swamp located to the east of the investigation site (Figure 2). The investigation area is located in a wooded setting consisting of scrub pine, white pine, northern red oak, and white oak with an understory of low-bush blueberry and gooseberry. The area has not been known for agricultural production, but has likely been logged at least once. Boa Swamp had been used for production of peat in the early 20th century. Based on the soil development and the expression of subsurface horizons, the soil has been relatively undisturbed by human activity.

3. BACKGROUND

Soils are natural bodies as defined in *Soil Taxonomy* (Soil Survey Staff, 1999) that are composed of solids (mineral and organic materials), liquids, and gases that occur on the land surface, occupy space, and are characterized by either horizons (layers) that are distinguishable from the parent material (original

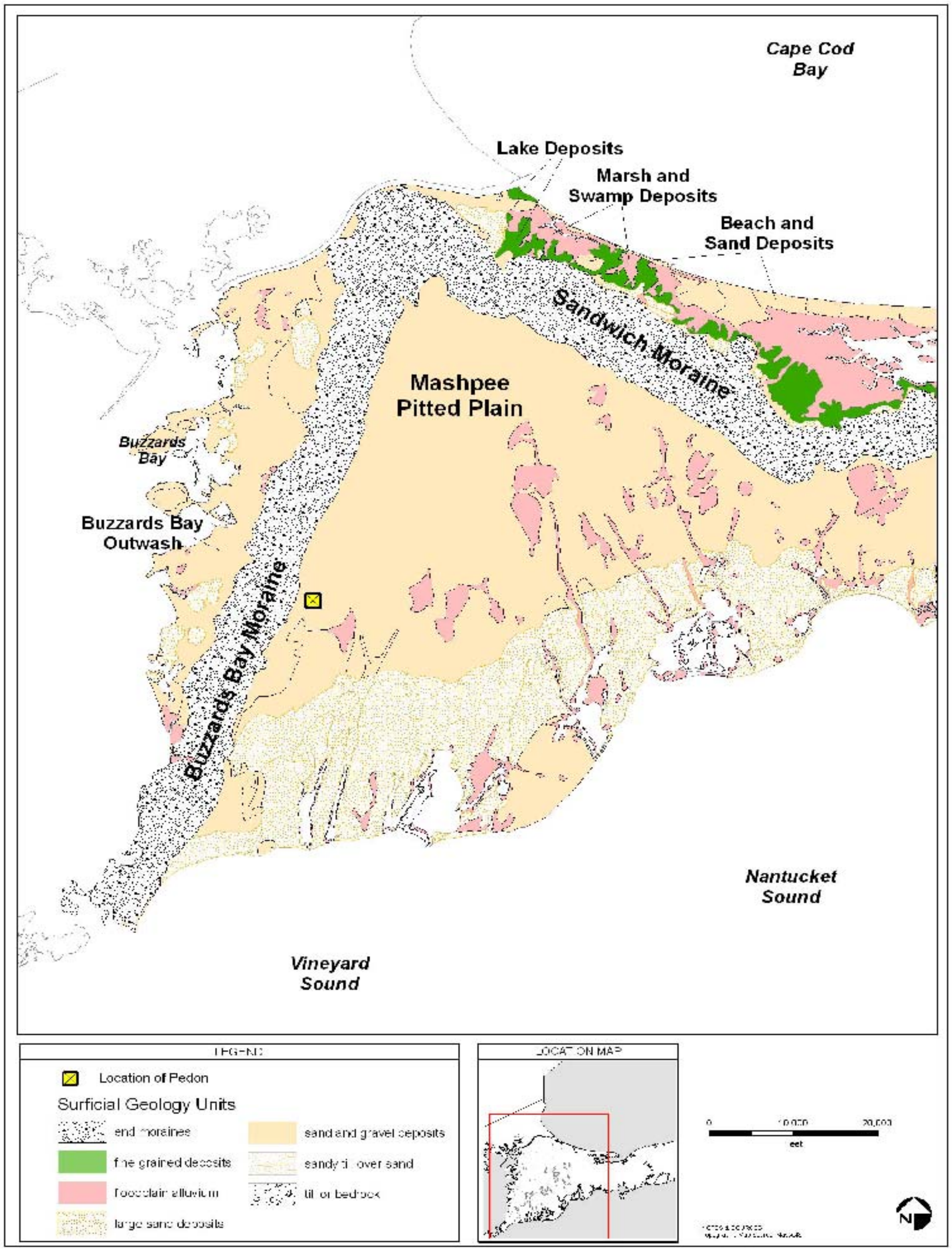

Figure 1. Cape Cod geology.

Figure 2. Location of Falmouth soil investigation.

material) as a result of additions, losses, transformations, and/or translocations of energy and matter; or the ability to support rooted plants in a natural environment.

The challenge in defining the variability in the soil is not only how to define these natural bodies, but also how to quantify the constituents within the soil. For example, soil amendments such as lime or fertilizer require a knowledge of the soil surface across a two-dimensional area of given depth to determine the quantities required to produce a crop without under- or over-amending the soil. For soil contamination, it is necessary to understand the distribution of contaminants across a soil area in order to more effectively develop a strategy for remediation. There have been a number of studies that show how soil constituents can be quantified across a soil area (Jenkins, et al., 1997; Jenkins, et al., 1999; Hewitt et al., 2005; Jenkins, et al., 2006). However, there are fewer studies on how these soils vary across an area at depth (Hewitt et al., 2007). In this investigation, three soil characterization methods will be used to define soil variability at depth: the pedon approach, and two compositing approaches; the multiple increment approach and the five-point composite approach.

The USDA-NRCS pedon approach is used primarily by soil scientists for the development of soil maps, usually on a county level survey. A pedon as defined in *Soil Taxonomy* (Soil Survey Staff, 1999) is a unit of sampling within a soil. The pedon is considered the smallest body of soil large enough to represent the nature and arrangement of horizons. A pedon has three dimensions, and its lower limit is the arbitrary limit between the soil (pedogenically altered material) and the non-soil (parent material). Its lateral dimensions are large enough to represent the nature of any horizons and variability that may be present across space. The minimal areal extent of a pedon is roughly 1 m^2, but can range to 10 m^2 depending on the variability in the soil across space. The polypedon is a unit of soil classification homogeneous at the soil series level and large enough to exhibit all the soil characteristics considered in the description and classification of soils (Soil Survey Staff, 1993). In practice, soil scientists generally use the pedon as the central concept of the polypedon or soil mapping unit. The pedon incorporates soil properties, site setting, vegetation, engineering properties, etc. into consideration of the mapping unit. Therefore, the pedon is the prototype of the soil that is characterized and mapped in space.

The second approach considered in this investigation is the multiple increment approach. While the pedon approach is more of a discrete sampling approach, the multiple increment approach is used to characterize surface soils for amendments and/or soil contaminants. In this approach, an area of interest or decision unit is identified and a number of "increments" of subsamples are collected and composited into a single sample. These samples can be collected using a random sampling or grid technique allowing for adequate coverage of the investigation area. In agricultural studies, it is recommended that 15 to 30 individual cores within an investigation area be collected to develop a representative sample (Clay et al., 2008). Multiple increment samples have also been used in studies of military ranges to characterize surficial deposition of explosives in and around military targets. Many of these studies have occurred in association with the Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire (Hewitt et al., 2007), but have also been used in Canada (Thiboutot et al., 2004), Alaska (Walsh et al., 2005), and Louisiana (Jenkins et al., 2005). The approach used at CRREL is a systematic grid sampling approach (USEPA, 2002) where a decision unit is defined and a grid is established to sample surface soils across that area. In this method, a number of sub-samples (or increments) are collected across a decision unit, usually consisting of short cores 2-3 cm in depth that are composited into a single sample to represent the soil surface of that decision unit (Hewitt et al., 2007). The rationale for using this approach is to reduce the amount of variability between samples in a decision unit. The technique was developed to address the heterogeneous distribution of explosive particles on the surface of soils in the areas of targets and firing points (Jenkins et al., 2000a, 2000b, 2001a, and 2001b). It has been noted that discrete samples in these target areas often yield results that are not reproducible and fail to adequately account for all explosive mass that may be present in and around these target areas. A multiple increment strategy yields more reproducible results and provides estimates of contaminant mass that are suitable for the development of conceptual site models and support risk assessments for surface soils (Hewitt et al., 2007; Jenkins et al., 2005).

A third method used for sampling soils in both the horizontal and vertical dimensions is the five-point composite approach (AMEC, 2003). The five-point composite approach uses a five-point configuration where an 11 x 11 foot (ft) square is established with four points plus an additional point in the center of the square. Each point is sampled with a bucket auger at arbitrary depths, and each point is composited with the other four for the same depth interval. In theory, the five-point composite characterizes an area 22 x 22 ft to a depth designated at the time of sampling.

All three soil characterization field methods can be used for surface soils. However, has been some discussion on the utility of the multiple increment approach in characterizing soils at depth (Hewitt et al., 2007). The pedon approach characterizes soils at depth based on properties observed in the soil profile where the investigator describes the natural horizons as they occur; but the multiple increment approach was designed for surface soils and, in most cases, at very small vertical intervals (1-3 cm). This method was designed to evaluate the mass of explosive particles that are heterogeneously dispersed across a soil surface in the vicinity of range targets. The limitations of using the multiple increment method with depth has been noted, and some recommendations include reducing the number of increments in a decision unit (Hewitt et al., 2007). It has also been cautioned that subsurface characterization across large decision units results in considerable uncertainty (Hewitt et al., 2007). The U.S. Environmental Protection Agency (USEPA) has suggested that multiple increment samples can be collected at depth based on the type of target (e.g., grenade ranges and disposal areas) where energetics can be found below the surface (USEPA, 2006). However, other agencies have recommended not applying the multiple increment approach to soils at depth greater than six inches (USACE, 2009). In general, the multiple increment approach has not been tested extensively for soil contamination at depths greater than those characterized for surface soils. The five-point composite approach does evaluate soils at depth, but it does so only at arbitrary intervals that are pre-determined (AMEC, 2003). The purpose of this investigation is to compare the three methods and evaluate how they characterize a soil at depth.

4. METHODS AND MATERIALS

The investigation was conducted on a small plot in a wooded area in Falmouth, Massachusetts. A study area was plotted that was 22 x 22 ft in area consistent with the dimensions of a soil grid based on the five-point composite approach (AMEC, 2003). A series of 30 points were established within this 22 x 22 ft grid. The 30 points were selected based per Hewitt et al. (2007); i.e., decision units less than 100 m^2 require only 30 increments for characterization. The method deviates from Hewitt et al. (2007) in that each point was measured and marked rather than placed at the discretion of the sampler walking in a serpentine pattern along the rows of each grid line. A diagram of the grid is presented in Figure 3, and the site grid is presented in Figure 4. After the grid was established, samples were collected using a 1 in. stainless steel push probe. Arbitrary depths of 0-3 in, 3-6 in, 9-12 in, 21-24 in, and 33-36 in were selected for the samples. For each interval, with the exception of the first, a 2.5 inch bucket auger was used to clean a hole for each sample increment. This was done to avoid cross-contamination of samples at depth. The 30 increments from each depth were composited into a single sample container. All soil collected from the 30 increments were included in the sample per Hewitt et al. (2007).

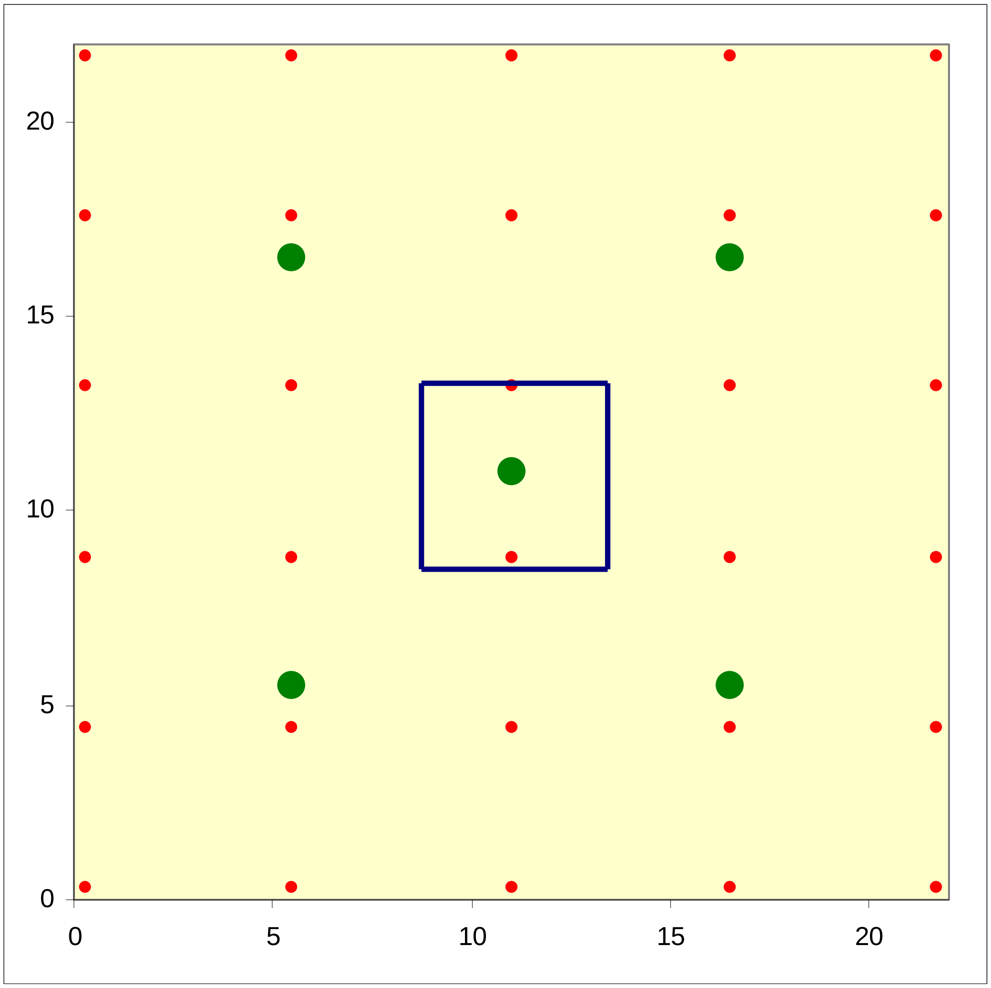

Figure 3. Diagram of soil sample locations within the 22 x 22 ft investigation area for multiple increment, five-point composite, and pedon.

Figure 4. 30 point grid in investigation area.

For the five-point composite approach, an 11 x 11 ft grid was established with the 22 x 22 ft decision unit (Figure 3). This included four points on the corners of the 11 x 11 ft grid and a point located in the center of the grid (Figure 3). Samples were collected at the arbitrary depths of 0-3 in, 3-6 in, 9-12 in, 21-24 in, and 33-36 in. A 2.5 in bucket auger was used to collect these samples. The five subsamples from each depth interval were composited into a single sample.

After completion of sampling by the multiple increment and five-point composite methods, a 1 x 1 m soil pit was excavated within the 22 x 22 ft grid unit (Figure 3). The pedon was described and sampled based on methods outlined in the *Soil Survey Manual* (Soil Survey Staff, 1993). A photograph of the finished pedon is presented in Figure 5.

Collected samples were subjected to particle size analysis and organic carbon analysis. The samples were air dried and ground to pass a 10 mesh sieve (2.00 mm limiting diameter). The particle size analysis consisted of a combination of sieving and sedimentation techniques as outlined in Gee and Bauder (1986). Samples with greater than 1 percent organic carbon were pretreated with a 30 percent H_2O_2 solution. Approximately 10 g of the less than 2.00 mm fraction of

Figure 5. Soil pedon in investigation area.

each sample was dispersed in Na-hexametaphosphate-Na-carbonate solution, and the sand size fraction of each sample was separated from the smaller fractions by wet sieving. The sand fraction was dried and fractionated by dry sieving into very coarse sand (2.00-1.00 mm), coarse sand (1.00-0.50 mm), medium sand (0.50-0.25 mm), fine sand (0.25-0.10 mm), and very fine sand (0.10-0.050 mm) fractions. The remaining silt and clay size fractions of each sample were retained in a 1000 ml capacity sedimentation cylinder and placed in a water bath. Pipette analysis was performed on these samples to determine silt (50-2 μm) and clay (less than 2 μm). Organic carbon was determined using the Walkley Black method (Nelson and Sommers, 1996).

5. RESULTS

The pedon for this investigation is presented in Figure 6, and the description of the pedon is presented in Table 1. The soil exhibits an organic layer (5-0 cm) that is situated on the surface of the soil pedon. According to soil survey convention, the contact between a surface organic layer and the underlying mineral layer is the origin of the soil description or 0 cm. The organic layer was highly decomposed, and those parts that could be identified consisted of oak leaves and pine needles. Below the organic layer was a transitional AE horizon that showed properties of a surface horizon with properties of an albic or eluvial horizon. The horizon is thin (4 cm), has a dark grayish brown (10YR 4/2) color, and a loamy coarse sand texture. Below the AE horizon is an eluvial horizon (E) that exhibits a lighter color (light brownish gray, 10YR 6/2) and is thin (3 cm). The lighter colors indicate a horizon from where organic materials plus aluminum and iron sequioxides have leached due to the combination of coarse textures and the chelating effect of acid-producing vegetation. The removal of these soil constituents is evident in the underlying Bhs_1 horizon which exhibits darker and redder colors (dark reddish brown, 5YR 3/3). These colors indicate translocation of humus and iron with depth from the AE and E horizons. This is also evident in the thin reddish coatings noted on the ped faces in this horizon. The lower boundary is wavy and, in some cases, irregular with fingers of this material noted as deep as 38 cm. However, the horizon is approximately 3 cm thick in general. This translocation of humus plus aluminum and iron sequioxides is a pedogenic process known as podzolization and is commonly found in coarse textured soils that form in environments with fulvic acid-producing vegetation (Stobbe and Wright, 1959; McKeague and St. Arnaud, 1969; Petersen, 1976). The underlying horizon, or Bhs_2 horizon, is also an illuvial horizon where translocation of humus and sequioxides are apparent in the morphology. The horizon is lighter in color than the overlying horizon (strong brown 7.5YR 5/6) with the redder colors represented as mottles (yellowish red, 5YR 4/6). The consistence in this horizon is more firm in the mottled zones and indicates an accumulation of iron sesquioxides. This horizon is thicker (18 cm) than the overlying horizons and does not have the wavy lower boundary noted in the Bhs_1 horizon. The BC horizon is a transitional horizon and exhibits the combined morphological characteristics of the glacial outwash parent material and the pedogenically altered soil material. This horizon is lighter in color (strong brown, 7.5YR 4/8) and has a texture (loamy coarse sand) similar to the overlying horizons. This horizon is thicker (21 cm) with a friable consistence. The soil structure is weak subangular blocky, which is weaker than the structure in the overlying horizons, but still indicates soil properties dominating over the looser parent material. The CB horizon exhibits more parent material properties and less soil properties than the BC horizon. The horizon is lighter in color (yellowish brown, 7.5YR 5/6) and the texture is coarser (coarse sand) than the more loamy overlying horizons. It was noted that many upland locations in Barnstable County have a 1 to 4 ft thick layer of silty loess on the surface (Fletcher, 1993). This pedon has more loamy textures in the upper horizons to a depth of 59 cm. This probably represents a loess cap that is partially in place in the upper horizons and may have translocated to the lower horizons. The CB horizon is looser in consistence and is lacking in mottles, coatings, and concretions. There are also few rounded gravels present in this horizon. The C horizon is the parent material and consists of pedogenically unaltered glacial outwash. This horizon is lighter in color (brownish yellow, 10YR 6/6) and has no soil structure (structureless single grain). The color is due primarily to the expression of the rounded quartz sand grains. In addition, there are more rounded gravels and cobbles in this lower horizon. There was also some remnant fine stratification in the lower portion of the pedon. This horizon had no coatings, mottles, or concretions noted.

Laboratory results for the soil pedon are presented in Table 2. The distribution of particle size and organic carbon with depth help to illustrate the pedogenic processes that are represented in the soil profile. Analysis shows that between 33 and 44 percent of the sand fraction is a coarse sand, which is consistent with soils derived from glacial outwash. The clay content is relatively uniform with an increase from 3.29 to 7.42 percent between the Bhs_2 and the BC horizons. The increase is likely due to the parent material because there is no evidence of illuviation of clay in the profile at that depth. The parent material (C horizon) is more than 90 percent sand with much less silt and clay. The silt fraction is the most revealing of the three particle size types because it represents the addition of loess on top of the glacial outwash and comprises between 15 and 22 percent silt content in the matrix. The silt profile decreases between the AE and E horizons from 15.29 to 14.56 percent and increases again to 21.46 percent in the Bhs_1 horizon. This shows that some silt is moving from the AE and E horizons into the lower horizons as a consequence of translocation of silt particles with infiltrating water (Figure 7). The silt content decreases in the Bhs_2 horizon (17.51 percent) and again in the BC horizon (14.48 percent). This decrease in silt content with depth indicates the limit of silt translocation in this particular medium. The parent

Figure 6. Soil pedon and horizons.

Table 1. Pedon description.

Area:	Falmouth, Barnstable County, Massachusetts
Classification:	Typic Quartzipsamments
Location:	70°34'53" W, 41°37'51"N
Native Vegetation:	northern red oak, white oak, white pine, scrub pine, lowbush blueberry
Physiography:	upland outwash plain
Parent Material:	loess over glacial outwash
Elevation:	81 ft
Infiltration:	rapid
Available Water:	low
Hydraulic Conductivity:	high
Soil Wetness Class:	class 1
Soil Slope:	nearly level
Erosion:	none to slightly eroded
Surface Runoff:	very slow
Sampled by:	Michael Morris, 16 November 2008

Horizon	**Depth (cm)**	**Description**
Oa	5-0	highly decomposed organics consisting of oak leaf and pine with a sphagnum consistence; very dusky red 2.5YR 2.5/2
AE	0-4	dark grayish brown 10YR 4/2 (moist) loamy coarse sand; weak fine subangular blocky structure; loose consistence; clear, smooth boundary; common medium roots; common fine pores; no mottles or concretions; no coatings on ped surfaces; displays some salt and pepper characteristics of organic plus sand
E	4-7	light brownish gray 10YR 6/2 (moist) loamy coarse sand; weak, fine subangular blocky structure; very friable consistence; no concretions; no coatings; common fine and few medium roots; common fine pores; one fingering of albic material; extended as deep as 17 cm; clear, smooth boundary
Bhs_1	7-10	dark reddish brown 5YR 3/3 (moist) loamy coarse sand; moderate medium to fine subangular blocky structure; friable consistence; very thin, discontinuous coatings on ped faces (segregated iron); very few fingers of this material as deep as 38 cm; white, rounded quartz grains are visible in peds; common fine and few medium roots; clear, wavy boundary
Bhs_2	10-28	strong brown 7.5YR 5/6 (moist) loamy coarse sand with common medium mottles of yellowish red 5YR 4/6; moderate, medium, subangular blocky structure; friable to firm consistence, firm particularly in the mottled zones; common fine roots; common fine and medium pores in the root zones; clear, smooth boundary
BC	28-49	strong brown 7.5YR 5/8 (moist) loamy coarse sand; few fine rounded quartz gravels; weak coarse subangular blocky structure; friable consistence; no concretions; no coatings; few fine roots; few fine pores; clear, smooth boundary

Table 1. Pedon description. (con't)

Horizon	**Depth (cm)**	**Description**
CB	48-73	yellowish brown 10YR 5/6 (moist) coarse sand; weak medium subangular blocky structure; friable to loose consistence; no coatings; no concretions; few fine rounded quartz gravels; few fine roots; few fine pores; clear, smooth boundary
C	73-103+	brownish yellow 10YR 6/6 (moist) coarse sand, color derived primarily from expression of quartz grains; common medium rounded quartz and granite gravels with few rounded quartz and granite cobbles; structureless single grain structure; very few fine roots; no visible pores; no concretions; no coatings

material (CB and C horizons) contains considerably less silt (7.65 and 3.01 percent, respectively). The translocation of silt sized particles has been documented in bench scale studies and is generally more prevalent in soils with coarser sand textures (Wright and Foss, 1968). This particular soil pedon likely represents a soil developed from glacial outwash with a loess cap that has been mostly eroded from the soil surface and partially translocated into the sandy matrix.

The organic carbon analysis of the pedon also shows the evidence for podzolization. The Oa horizon is defined as one that has well decomposed organic material that comprises more than 50 percent of the soil matrix (Soil Survey Staff, 1993). This is why the organic carbon content was not determined for this horizon (Table 2). The organic carbon content decreases considerably in the AE horizon to 0.75 percent, but represents the highest organic carbon content of the mineral horizons (Figure 8). There is another considerable decline in organic carbon content in the E horizon which represents some translocation of organic matter from the E horizon into the underlying horizons. This is shown by the increase in organic carbon in the Bhs_1 horizon to 0.42 percent and the greater increase in the Bhs_2 horizon to 0.54 percent. This increase represents organic matter than has been translocated from the upper A and E horizons into the lower horizons. In horizons below the Bhs_2 horizon the organic carbon content decreases by almost half (0.27 to 0.25 percent). This decrease may represent some translocation but may also be indicative of carbon that occurs naturally in the parent material. This is more evidence that the pedogenic process of podzolization is active at this site.

Table 2. Laboratory results.

Sample	Lower Depth	Organic Carbon	Sand	Silt	Clay	VCoS	CoS	MS	FS	VFS	USDA
	Ft	%	%	%	%	%	%	%	%	%	
Oa	0.16	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AE	0.29	0.75	81.73	15.29	2.98	7.12	35.61	23.46	22.91	10.90	LCoS
E	0.39	0.42	81.48	14.56	3.96	7.37	34.83	23.96	22.92	10.92	LCoS
Bhs_1	0.49	0.49	76.03	21.46	2.51	8.15	33.35	23.31	21.73	13.46	LCoS
Bhs_2	1.11	0.54	79.20	17.51	3.29	14.43	41.15	21.53	14.54	8.34	LCoS
BC	1.77	0.27	78.10	14.48	7.42	13.25	36.06	21.89	18.55	10.25	LCoS
CB	2.56	0.20	86.46	7.65	5.89	13.01	36.19	20.53	20.42	9.84	CoS
C	3.54	0.25	92.73	3.01	4.26	18.81	43.55	18.72	14.48	4.44	CoS
MI 1	0.25	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MI 2	0.50	1.44	77.79	17.82	4.39	14.11	30.75	22.98	22.38	9.78	LCoS
MI 3	1.00	0.40	76.90	13.46	9.64	11.16	33.58	22.56	23.95	8.75	LCoS
MI 4	2.00	0.31	78.60	13.13	8.27	10.73	28.72	23.71	24.03	12.81	LCoS
MI 5	3.00	0.25	86.80	8.62	4.58	10.24	28.67	22.82	23.72	14.55	CoS
5-pt 1	0.25	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5-pt 2	0.50	0.18	78.29	12.69	9.02	12.26	29.40	24.88	23.21	10.24	LCoS
5-pt 3	1.00	0.49	75.17	16.3	8.53	9.79	31.26	21.63	24.53	12.79	LCoS
5-pt 4	2.00	0.39	79.54	13.68	6.78	12.69	34.34	21.19	18.39	13.39	LCoS
5-pt 5	3.00	0.51	86.75	9.88	3.37	30.04	20.93	18.56	19.61	10.86	CoS

ft = feet
MI = multiple increment
5-pt = five-point composite
% = percent
Sand = 2.00-0.050 mm
Silt = 0.050 mm – 2 µm
Clay = < 2 µm
USDA = U.S. Department of Agriculture

VCoS = very coarse sand, 2.00-1.00 mm
CoS = coarse sand, 1.00-0.50 mm
MS = medium sand, 0.50-0.25 mm
FS = fine sand, 0.25-0.10 mm
VFS = very fine sand, 0.10-0.050 mm
LCoS = loamy coarse sand
NA = not analyzed due to high organic carbon content

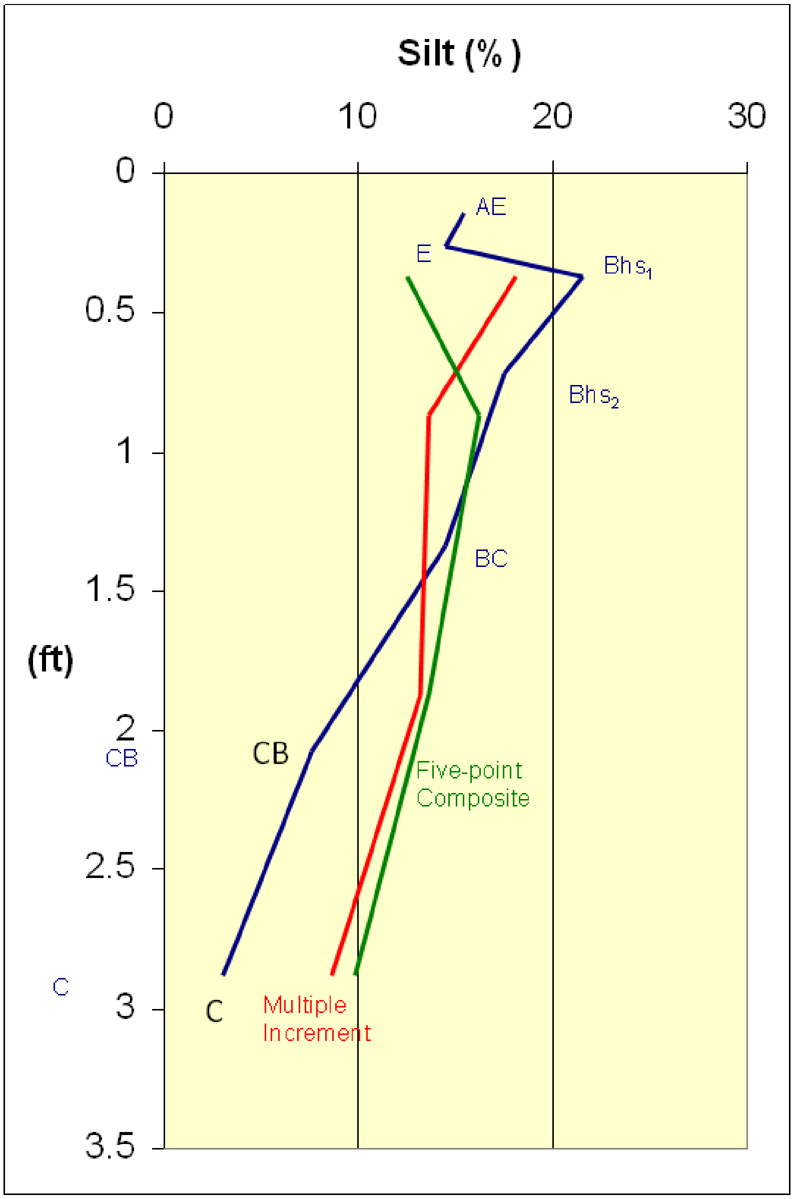

Figure 7. Silt content with depth for pedon, multiple increment, and five-point composite approaches.

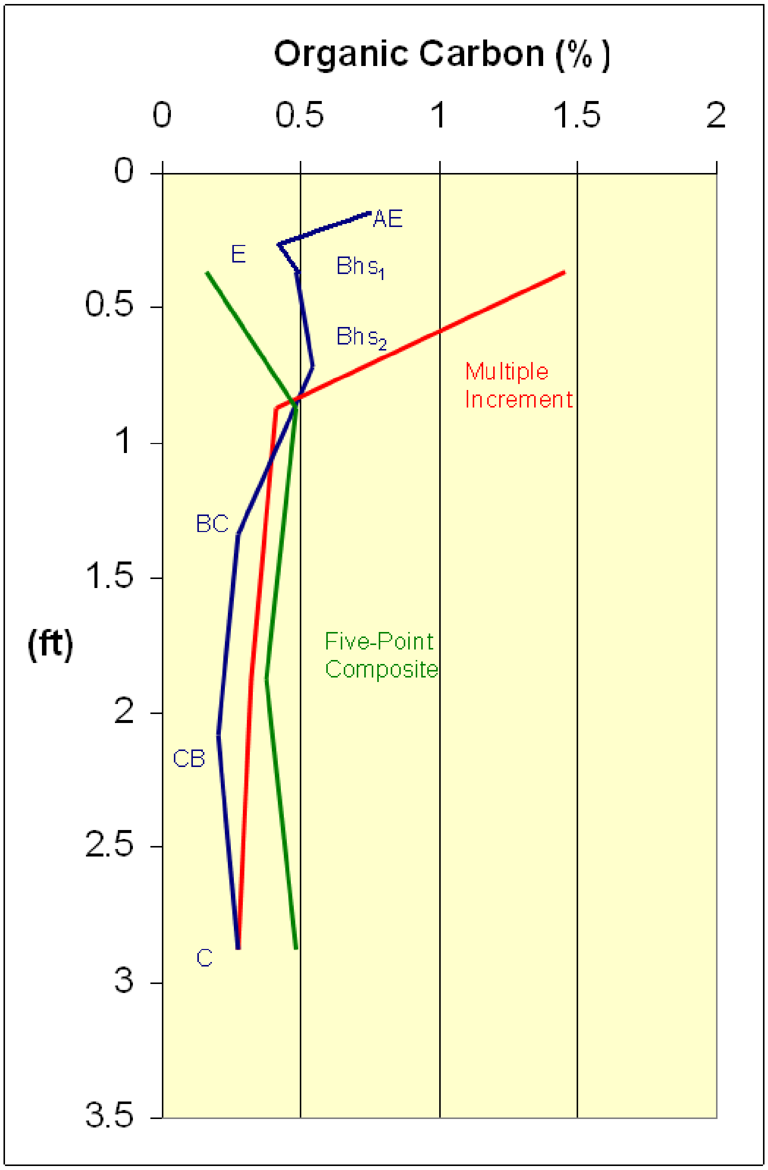

Figure 8. Organic carbon content with depth for pedon, multiple increment, and five-point composite approaches.

The multiple increment approach used arbitrary intervals for characterizing the soil decision unit. As expected, the physical descriptions and laboratory analytical results indicate a profile that is a homogenized version of the pedon approach results. The 0-3 in interval has the dark color of the organic matter (dark reddish brown, 5YR 2.5/2) but shows some mixing with the underlying mineral horizon expressed as white sand grains (Table 3). This is expected because the organic horizon is less than 3 inches thick (approximately 2 inches). The 3-6 in interval intercepts at least three soil horizons (AE, E, and Bhs_1), and this is evident in the mix of colors described in this interval including brown (10YR 3/2, AE horizon), very dark grayish brown (10YR 3/2, E horizon), and strong brown (7.5YR 5/6, Bhs_1 horizon). The texture of loamy coarse sand is consistent with these three horizons. The 9-12 in interval would represent one illuvial horizon (Bhs_2) and one transitional horizon (BC). The moist color is strong brown (7.5YR 5/6) and is consistent with the Bhs_2 horizon, and the loamy coarse sand texture is consistent with both horizons. The 21-24 in interval would correlate with the CB transitional horizon and has a brownish yellow color (10YR 6/6) and a weak medium subangular blocky structure which is also consistent. However, the loamy coarse sand texture is not consistent with the CB horizon's coarser texture. The 33-36 in interval correlates with the C horizon and has a light yellowish brown color (10YR 6/4) and a coarse sand texture that is consistent. The consistence is loose, and the sample contained common rounded quartz gravels. The C horizon has this, but also contains rounded quartz cobbles that would be too large to sample with a 1 in push probe. In general, the multiple increment approach does not account for the subtle variability in the surface soil horizons.

The laboratory analyses for the multiple increment approach also show that the method homogenizes the soil (Table 2). The coarse sand fraction is still shown to be dominant using this approach, but it only varies between 29 and 34 percent in the column. The silt content in the intervals varies from the samples collected in the pedon approach (Figure 7). The finer textures that would indicate possible presence of residual loess in the soil are present in the 3-6 in interval at 17 percent, which is consistent with the top three mineral horizons of the pedon; however, the subtle translocation of silt in the profile is missed due to the larger sampling interval. Additionally, the 21-24 in interval shows a silt content of approximately 13 percent, which is double what the pedon shows at the same interval (CB horizon, 8 percent silt). Even the lowest interval of 33-36 in shows triple the silt content (9 percent) of the corresponding C horizon (3 percent). One possible explanation for this phenomenon is cross-contamination of soil samples in the lower horizons with the upper horizons as a result of poor bore-wall integrity and increased traffic across the study area to collect 30 subsamples.

Table 3. Soil description for multiple increment sampling approach.

Area:	Falmouth, Barnstable County, Massachusetts
Sampled by:	Michael Morris and Aimee Comeau, 9 November 2008
Depth (in)	**Description**
0-3	dark reddish brown (5YR 2.5/2) organic material with flecks of white quartz sand with common medium mottles of dark brown (10YR 3/3); weak medium crumb structure; common fine and medium roots
3-6	brown (10YR 5/3) loamy coarse sand with common medium mottles of strong brown (7.5YR 5/6) and very dark grayish brown (10YR 3/2); weak fine crumb structure; common fine roots, very friable consistence
6-9	no description
9-12	brownish yellow 7.5YR 5/6 loamy coarse sand; medium fine subangular blocky to structureless single grained structure; few fine and medium roots
12-21	no description
21-24	brownish yellow (10YR 6/6) loamy coarse sand with few fine brownish yellow (10YR 6/8) mottles; weak fine subangular blocky to structureless single grain structure; very friable; few fine roots
24-33	no description
33-36	light yellowish brown (10YR 6/4) coarse sand; structureless single grain structure; loose consistence; no visible roots; common fine rounded quartz gravels

The organic carbon content in the multiple increment approach shows some signs of cross-contamination as well. The first interval (0-3 in) had too much organic matter to measure using the Walkley Black method (Nelson and Sommers, 1996) (Table 2). However, the 3-6 in interval had an organic carbon content of 1.44 percent which is almost double the highest of the top three mineral horizons in the soil pedon (Figure 8). Although the lower intervals are more consistent with the pedon, the 21-24 in interval is slightly elevated in comparison to the pedon organic carbon content (0.31 percent compared to 0.20 percent in the CB horizon). If the organic horizon on the surface were contamination, this would show that the soil was contaminated for at least the top 6 inches rather than in the top 3 inches as the pedon would indicate.

The five-point composite approach also homogenized the soil in comparison to the pedon approach. The 0-3 in interval is a dark black (5YR 2.5/1) organic horizon that is consistent with the Oa horizon of the pedon and has a fraction of AE's mineral horizon mixed into it (Table 4). The 3-6 in interval is a mixture of the top three mineral horizons described in the pedon as revealed by the multiple colors. The dominant color is strong brown (7.5YR 5/6), which is consistent with the Bhs_1 horizon and is mottled with very dark grayish brown (10YR 3/2) of the AE horizon and grayish brown (10YR 5/2) of the E horizon. The loamy coarse sand texture is also consistent with these three horizons, and the subangular blocky structure shows some remnant soil structure in the upper mineral horizons. The 9-12 in interval exhibits a strong brown color (7.5YR 4/6) and a loamy coarse sand texture, which is consistent with the Bhs_2 horizon. However, there is no structure left in the sample, and that is not consistent with the Bhs_2 or BC horizon. The 21-24 in interval has a yellowish brown color (10YR 5/6) that is consistent with the CB horizon, but the lack of soil structure and the loamy coarse sand texture is not consistent. The 33-36 in interval has a brownish yellow color (10YR 6/6), a coarse sand texture, and a structureless single grain structure that is consistent with the C horizon.

Table 4. Soil description for five-point composite sampling approach.

Area:	Falmouth, Barnstable County, Massachusetts
Sampled by:	Michael Morris and Siobhan Morris, 14 November 2008
Depth (in)	**Description**
0-3	black (5YR 2.5/1) organic plus sand mixture; many medium and fine roots
3-6	strong brown (7.5YR 5/6) loamy coarse sand with many medium grayish brown (10YR 5/2) and very dark grayish brown (10YR 3/2) mottles; weak fine subangular blocky structure; common fine and medium roots
6-9	no description
9-12	strong brown (7.5YR 4/6) loamy coarse sand; structureless single grain structure; very friable to loose consistence; common fine roots
12-21	no description
21-24	yellowish brown (10YR 5/6) loamy coarse sand; structureless single grain structure; loose consistence; few fine roots
24-33	no description
33-36	brownish yellow (10YR 6/6) coarse sand; structureless single grain structure; loose consistence; very few fine roots

The laboratory analysis results for the five-point composite approach are similar to that observed for the multiple increment approach (Table 2). The major particle size fraction is sand (75 to 87 percent) with coarse sand dominating (21 to 34 percent). The silt profile is somewhat consistent with the pedon, but does show some elevated contents in the lower portions of the profile (Figure 7). The 3-6 in interval has a silt content that is comparable to the E horizon of the pedon (13 and 15 percent, respectively). The 9-12 in interval is also consistent with the Bhs_2

horizon with silt contents of 16 and 18 percent, respectively. However, the 21-24 in interval's silt content is almost double that of the CB horizon (14 and 8 percent, respectively). The 33-36 in interval's silt content is also elevated (10 percent) compared to the corresponding C horizon (3 percent). This shows the possible cross-contamination of samples that was observed in the multiple increment approach. Borehole integrity would also be an issue with the five-point composite approach, particularly in sandy, unstable soils.

The organic carbon content of samples collected using the five-point composite approach shows some enrichment of organic carbon with depth compared to the pedon approach. The first interval (0-3 in) had too high an organic carbon content to measure with the Walkley Black method (Nelson and Sommers, 1996), consistent with the Oa horizon (Table 2). The 3-6 in interval, however, had an anomalously low organic carbon content (0.18 percent) that was well below the lowest of the upper three mineral horizons (E horizon, 0.42 percent) (Figure 8). The 9-12 in interval (0.49 percent) is consistent with the Bhs_2 horizon (0.54 percent). The 21-24 in (0.39 percent) and 33-36 in (0.51 percent) intervals are double their corresponding mineral horizons (0.20 and 0.25 percent, respectively). These results indicate that there could be some cross-contamination of samples with depth using the five-point composite method.

6. DISCUSSION

The soil description for the pedon approach was used to establish the taxonomy of the soil pedon. The primary consideration in classifying this pedon was whether the illuvial horizons (Bhs_1 and Bhs_2) qualified as spodic horizons, the diagnostic horizon of the Spodosols order. The illuvial horizons did not meet the criteria for a spodic horizon because neither had an organic carbon content greater than 0.60 percent (the Bhs_2 was 0.54 percent). This placed the soil in the Entisols order, and the subgroup was classified as a Typic Quartzipsamments (Soil Survey Staff, 2006). The Spodic Quartzipsamments was a possibility, but there was neither enough cementation in the illuvial horizon nor laboratory data to substantiate this classification. The soil in this soil mapping unit is classified as a Typic Quartzipsamment according to the soil survey conducted for Barnstable County (Fletcher, 1993). Therefore, the pedon description was consistent with the survey.

One of the considerations in the development of a conceptual site model is to determine the presence and/or intensity of soil disturbance in a soil decision unit. In this case, a soil that exhibits properties of podzolization has likely been undisturbed for a period of time. There are several ideas of how podzolizaton is expressed as a function of time. Schaetzl (2002) found that more intensive podzolization formed well developed Spodosols in areas of Michigan dominated by hardwood forest, low fire frequencies, and deep snowpacks in comparison to areas with jack pine and oak barrens with smaller snow packs that formed Psamments. Wang et al. (1986) found that Spodosols in Canada varied from enriched sequioxide and depleted organic matter content in the northern spruce forests to lower sequioxide and higher organic matter content in the southern maple forests. In glaciated terrain, Spodosols are relatively young. Spodosols have been estimated at 10,000 years in Sweden (Olsson and Melkerud, 1989), 3,000-8,000 years in Michigan (Franzmeier and Whiteside, 1963), and 500 years in Menomee, Wisconsin under hemlock vegetation (Hole, 1975). Podzols with well developed albic (E) horizons ranging in age from 230 to 11,300 years were studied in Finland (Buurman and Jongmans, 2005). Spodosol development was determined to be a minimum of 1,520 years to meet the organic matter content and 4780 years to meet the accumulation of sequioxides (Mokma et al., 2003). Therefore, to develop soils with the characteristics observed in the study pedon would require a minimum of 230 years. This relative time estimate would pre-date any recent activities on Cape Cod, including military training (with the exception of the Revolutionary War). Thus, if sampling were needed to quantify the amount of explosive residue across this decision unit, the sampling would only require a depth of a few inches to characterize the mass deposited across the site.

A separate study was conducted on the results of this method comparison. The organic carbon profiles of the three methods were used in a Seasonal Soil Compartment Model (SESOIL) (Bonazountas and Wagner, 1984; Hetrick et al., 1993) simulation to understand how contaminants might be transported through this profile assuming a surface deposition of readily available explosive compounds. Because of the great variability in the organic matter contents at the surface and the variability in the methods used to describe this organic layer, all three approaches assumed a uniform distribution of organic carbon (1.50 percent) in the top 3 in of soil. Table 5 shows the input parameters used in the simulation for each soil sampling method. In this exercise, the compounds hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) and 2,4,6-trinitroluene (TNT) were loaded into the surface of each profile for each soil method. The results showed that RDX was transported through the profile by 1.2 years in the pedon method compared to 1.4 years in the multiple increment and 1.5 years in the five-point composite approaches. TNT was transported through the profile in 1.1 years in the pedon approach as compared to 1.3 and 1.5 years in the multiple increment and five-point composite approaches respectively. The difference in these three methods is the enrichment of organic carbon with depth in the composite approaches which retards the transport of organic compounds through the soil profile. Therefore, for RDX and TNT, the pedon approach provides a more conservative estimate of transport and predicts a more rapid groundwater impact by these explosive compounds.

Table 5. Input parameters used in SESOIL analysis.

Source Thickness (cm)	4.06			
Source Area (cm^2)	450,000			
Contaminant	RDX		TNT	
Source Concentration (mg/kg)	126.5		126.5	
Water Solubility (mg/L)	59.7		130	
Diffusivity in Air (cm^2/s)	NA		0.0245	
Henry's Law Constant (m^3-atm/mole)	0.000000063		0.00000046	
Organic Carbon Partition Coefficient (L/kg)	195.4		1834	
Molecular Weight (g/mole)	222.12		227.13	
Source Loading Type	Instantaneous			
Number of Soil Layers	4			
	Layer-1	Layer-2	Layer-3	Layer-4
Layer Thickness (cm)	7.62	7.62	15.24	60.96
Number of Sublayer	4	8	5	10
Intrinsic Permeability (cm^2)	1.00E-08	1.00E-08	1.00E-08	1.00E-08
Soil Density (g/cm^3)	1.66	1.66	1.66	1.66
Disconnectedness Index	3.7	3.7	3.7	3.7
Porosity	0.3	0.3	0.3	0.3
Organic Carbon Content (percent) Pedon	1.50	0.49	0.54	0.24
Organic Carbon Content (percent) Multiple Increment	1.50	1.44	0.40	0.28
Organic Carbon Content (percent) Five-point Composite	1.50	0.18	0.49	0.45

cm = centimeters
cm^2 = square centimeters
RDX = hexahydro-1,3,5-trinitro-1,3,5-triazine
TNT = 2,4,6-trinitrotoluene
mg/kg = mg/kg
mg/L = milligrams per liter
cm^2/s = square centimeters per second
m^3-atm/mole = cubic meters –atmospheres per mole
L/kg = liters per kilogram
g/mole = grams per mole
g/cm^3 = grams per cubic centimeter
NA = not available

One of the primary differences among the pedon, the multiple increment, and the five-point composite approaches is the documentation of soil morphology. The assessment of soil morphology is critical to the pedon approach and aids in the interpretation of soil-forming processes. In contrast, both the multiple increment and the five-point composite approaches pay little or no attention to soil morphology. Because these approaches use arbitrary depth intervals, both methods assume that the soil is uniform across the increments for each depth interval. When applied to surface sampling, this is clearer because there is a well defined, natural boundary between the soil surface and the non-soil above the surface. However, as noted by the U.S. Army Corps of Engineers (2009), the uncertainty with depth is a major concern and should not be applied to any sampling effort other than surface characterization. If the 5 cm organic layer on the surface of this soil had been contamination, it could be interpreted in the multiple increment and five-point composite approaches that contamination was evident at 2 ft or more based on the carbon profile. These approaches also show that the silt content was enriched at depth when the pedon approach shows the higher silt contents much closer to the surface. This cross-contamination likely occurs as a result of the movement of soil materials from the surface to the sample below due to the instability of the walls of the soil borings. The pedon approach uses a clean soil profile, and sampling occurs from the bottom to the top to avoid this cross contamination of samples. Based on the profiles of the two composite methods, a disturbed soil could be interpreted based on the available data. The pedon approach, however, shows that the soil was not disturbed, the organic layer was clearly limited to the surface, and the translocation of organic carbon in the profile was natural (not due to human impact). The pedon approach focuses on soil morphology, makes interpretations based on the characteristics of the soil, and provides a more clear conceptual site model for the decision unit. This approach can be applied to disturbed soils as well because there are soil characteristics that are expressed in the profile due to soil-forming processes such as human activity or disturbance. Activities such as plowing, burials of items, burning, disposal, treatments, and amendments can be found in the morphology of the soil.

The multiple increment and five-point composite approaches do not address the position of the decision unit in the context of the landscape in considering the boundaries of a decision unit. Because the five-point composite approach considers only a relatively small unit, this aspect is not as critical because there is less chance that the unit will traverse a major physiographic boundary. In this investigation, for example, the decision unit was limited to an upland position with a nearly level terrain. However, the multiple increment approach can be applied to decision units as large as 2,500 m^2 (Hewitt et al., 2007). A unit this size could easily be placed across multiple soil or geomorphological units (upland, backslope, footslope, terrace, floodplain, etc.) that have different soil properties and require different conceptual site models to account for deposition and subsequent burial and transport. If such a large unit were used in this investigation, the unit would cross the upland into the backslope, footslope, and perhaps the toe slope and bottom (bog). Each of these landscapes have different factors regarding erosion, deposition, slope adjustment, and stability that would affect how a contaminant might express itself in the soil profile. A rule of thumb for placing large decision units across a landscape is the larger the decision unit, the greater the uncertainty. Therefore, a more detailed approach to soil morphology will provide a more detailed conceptual site model and in turn reduce the uncertainty of interpreting the impact of human activities (or lack thereof) in a soil at depth.

Another consideration is the time that is spent to characterize soils in a given decision unit. In this investigation, a relatively small decision unit (484 ft^2) located entirely in an upland position on a nearly level landscape was assessed. The soil was sandy and relatively stone-free making the excavation and coring of the soil relatively easy. For the pedon, it took one person approximately four hours to excavate, clean, photograph, describe, and sample. The five-point composite approach took one person approximately one hour to establish the grid, collect the soil samples, and take soil descriptions of the five samples. For the multiple increment approach, it took two people approximately five hours to establish the grid and collect and describe the five samples for a 30 increment composite. Given that the multiple increment and the five-point composite approaches were almost equally effective in cross-contaminating the soil samples with depth thus producing results of similar quality, the five-point composite approach would be the more cost effective of the two arbitrary interval, compositing approaches for characterizing this decision unit. The pedon approach provided much more information and is the established method for characterizing a given soil unit, making the time investment to reduce uncertainty more valuable. Therefore, applying a composite method to characterize anything but a soil surface would be meaningless without some knowledge of the soil morphology at depth of the decision unit under investigation.

7. CONCLUSIONS

A comparison of three soil characterization methods showed that among a USDA-NRCS pedon method, a multiple increment composite method, and a five-point composite method, the pedon method was the one that provided the most reasonable and complete information on soil variability at depth. The investigation of a 22 x 22 ft decision unit on a soil developed from loess over an upland glacial outwash plain showed that the soil had undergone podzolization with translocation of organic matter plus iron sesquioxides from the surface horizons into the subsoil horizons. This pedogenic process developed a soil with an irregular carbon distribution with depth. There is enrichment of organic matter in the surface horizon, depletion of organic matter in the albic horizon, and subsequent enrichment of organic matter in the illuvial horizons. Translocation of organic matter was estimated at approximately 1.0 ft in depth. A particle size analysis showed that a loess cap likely worked into the sandy outwash matrix and was partially translocated as a result of infiltrating water. Depth profiles compiled from both multiple increment and a five-point composite approaches showed that there was relatively little variability in organic carbon and silt with depth. Moreover, the compositing methods showed enrichment of organic carbon and silt with depth below 1.5 ft indicating cross-contamination of deep samples by shallow soils. This was likely due to instability of boreholes with depth in an unstable, sandy matrix. The pedon approach provided a more detailed assessment of soil variability with depth and a more comprehensive conceptual site model of depositional and post-depositional processes. The two compositing approaches were designed to evaluate soils with contaminants that were deposited as surface debris. It is recommended that the compositing approaches be used exclusively for characterizing surface soils only (0-3 cm). Care should be taken to limit the extent of these decision units to landscapes of similar physiographic characteristics. These compositing methods should only be used at depth in concert with the evaluation of soil morphology for any decision unit, particularly if trying to evaluate the nature and extent of soil contamination at depth.

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